A Study of Physicochemical Conditions, Phytoplankton and Microcrustacean Zooplankton in Wallerawang Reservoir, New South Wales

T. KOBAYASHI

(Communicated by B. V. TIMMS)

Wallerawang Reservoir is shallow (mean depth 3.4 m), mesotrophic and lacks persistent summer thermal stratification. During the period from April 1986 to September 1987, the depth-averaged temperature range was 7.6-23.4°C, oxygen 4.8-10.2 mgL^{-1}, pH 6.7-7.7 and total phosphorus less than 0.01-0.09 mgL^{-1}.

Dominant phytoplankton genera found in this reservoir (*Chroococcus, Asterionella, Attheya, Cyclotella, Stephanodiscus, Melosira* and *Dinobryon*) are generally characteristic of those in other unstratified, mesotrophic lakes of the region; the summer propagation of *Melosira* is attributed to increased temperature, lack of persistent thermal stratification, and moderately high silica during the period.

The common microcrustacean zooplankton species identified (*Bosmina meridionalis, Ceriodaphnia* sp., *Daphnia carinata, Calamoecia lucasi, Boeckella minuta*, and *Boeckella triarticulata*) are ubiquitous in south-eastern Australia.

The gut contents of the dominant microcrustacean zooplankton species reflect the reservoir phytoplankton composition; diatoms are generally better digested than the gelatinous blue-green algae ingested.

T. Kobayashi, River Studies Section, Scientific Services, Water Board, P.O. Box 73, West Ryde, Australia 2114 (formerly School of Biological Science, University of New South Wales, P.O. Box 1, Kensington, Australia 2033); manuscript received 10 July 1990, accepted for publication 20 February 1991.

INTRODUCTION

Wallerawang Reservoir, on Cox's River near Lithgow, was first filled in 1979. The reservoir provides water to the cooling tower of the adjacent power station.

A blue-green alga, *Microcystis aeruginosa* Kutz., an indicator of eutrophication (May, 1972; Okino, 1973), occasionally blooms in the reservoir in late summer and early autumn; some two thousand goldfish (*Carassius auratus*) died in Wallerawang Reservoir during a bloom of *Microcystis* in late summer 1983. However, it is not known if *Microcystis* caused the deaths or if some unknown pathogen caused mass mortality (J. Harris, B. Hodgson, 1988, pers. comm.).

A study of physicochemical conditions (transparency, temperature, oxygen, pH, phosphorus, nitrogen and silica) of the reservoir was conducted by the Electricity Commission (Elcom) of New South Wales, to assess the trophic status and possible eutrophication of the reservoir (Hodgson, 1987). There was no detailed study of the biological processes occurring within the reservoir which apparently governed the abundance of phytoplankton (particularly *Microcystis*). Therefore, there was a need to gain fundamental biological information, especially on plankton, to better manage reservoir water quality.

This paper presents the results of a study of physicochemical conditions, phytoplankton and microcrustacean zooplankton in Wallerawang Reservoir between April 1986 and September 1987. Features of particular interest are: the composition and seasonal abundance of dominant phytoplankton; the composition and seasonal

abundance of dominant microcrustacean zooplankton (cladocerans and calanoid copepods); diet (gut contents) of the microcrustacean zooplankton. These data display basic limnological data parameters of the reservoir.

STUDY AREA

The characteristics of Wallerawang Reservoir are summarized in Table 1. It is shallow, with short retention time. Cox's River, erratic precipitation and to a lesser extent recirculated water from Lyell Reservoir 16 km downstream, are the major sources of water inflow. Reservoir spill, discharge to the power station and release dominate the outflow. Each month about 18% of the reservoir volume is withdrawn and evaporated through the power station cooling tower (Hodgson, 1988, pers. comm.).

The reservoir is inhabited by six species of fish including rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*), although their density has not been measured (Harris, 1988, pers. comm.). A pond weed (*Potamogeton pectinatus*) is conspicuous in summer.

TABLE 1

Characteristics of Wallerawang Reservoir

Location	150°05′E., 33°25′S.
Elevation (above sea level)	870 m
Maximum length (l)	3.5 km
Maximum width (b)	1.4 km
Area (A)	$124.7 \times 10^4 \, m^2$
Volume (V)	$4.3 \times 10^4 \, m^3$
Maximum depth (z_{max})	8.0 m
Mean depth (z)	3.4 m
Shore line (L)	10.7 km
Shoreline development (D_L)*	2.7
Mean turnover rate	$6.4 \, year^{-1}$

* Hutchinson (1957).

METHODS

Physicochemical Parameters

To measure the water transparency, a 25 cm Secchi disc was lowered at station A (Fig. 1). Downward irradiance in the photosynthetically available radiation or PAR (400-700 nm waveband) was measured at station A as described by Kirk (1977). The instruments used were a Li-185A lightmeter (Lamda Instruments Corp., U.S.A.) and Li-192S underwater quantum sensor (L.I.C., U.S.A.: quantum response in 400-700 nm; sensor output in μEinst m^{-2} sec^{-1}). The depth-averaged vertical attenuation coefficient for downward irradiance (Kd(PAR)) (Kirk, 1986) was calculated by the least squares regression method (Zar, 1974).

Water temperature (°C) and dissolved oxygen (mg l^{-1}) were measured at station A at 1 m intervals to the bottom, using a portable dissolved oxygen/temperature meter (Model 603, Yeo-Kal Electronics Pty., N.S.W.) to the nearest 0.1°C and 0.1 mg l^{-1}, respectively.

Monthly data on pH, total phosphorus (TP as mg l^{-1}), nitrate plus nitrite (NO_3-N plus NO_2-N), ammonia (NH_4-N), and silica (SiO_2-Si) were provided by Elcom, N.S.W. All the data were collected near the surface at station A during daytime. Data on monthly rainfall in the Lithgow area was provided by the Bureau of Meteorology, N.S.W.
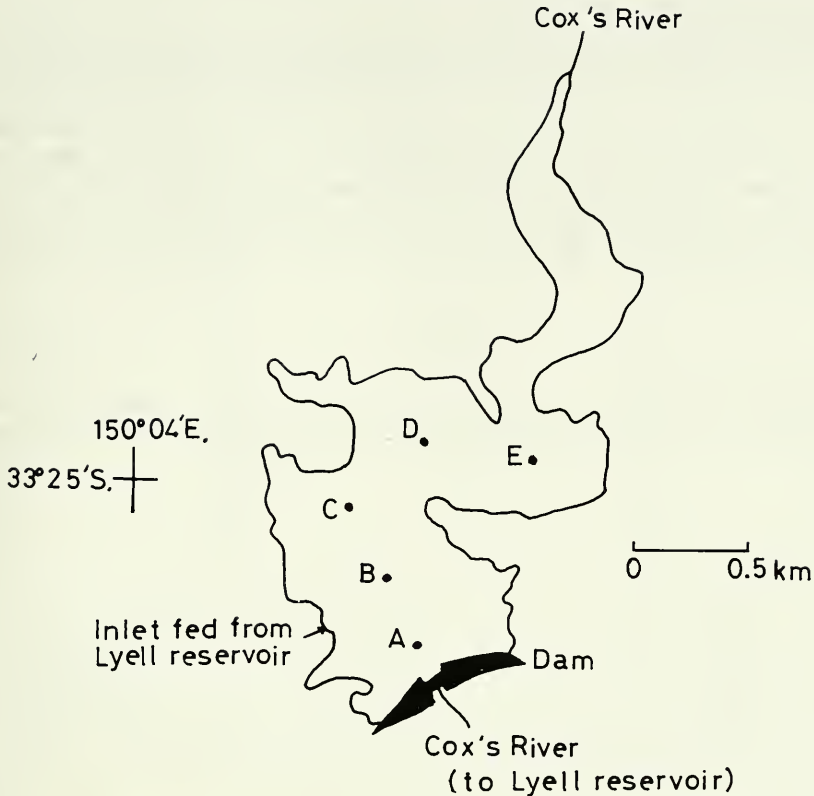
Cox 's River

150°04'E.

33°25'S.

D.

E.

C.

B.

0   0.5 km

Inlet fed from
Lyell reservoir

A.

Dam

Cox's River
(to Lyell reservoir)

Fig. 1. Sampling stations in Wallerawang Reservoir.

Phytoplankton

Phytoplankton was collected monthly at stations A to E at 0.5 m depth between
August 1986 and September 1987, using a 2-L Van Dorn water sampler. A single 500 ml
subsample was measured out in a graduated cylinder, and preserved with 0.4 ml Lugol's
iodine solution at each sampling station. Identification and counts of phytoplankton
were conducted using a Prior inverted microscope at a magnification of 100 x to 420 x.
Most phytoplankters were identified only to genus level, but some were taken to species.
A maximum of 100 cells or colonies of each genus were counted (Lund *et al.*, 1958). The
density of a phytoplankton genus (cells ml^{-1} or colonies l^{-1}) in the reservoir was calcu-
lated as the arithmetic mean of the densities of the genus at each sampling station.

Microcrustacean Zooplankton

Microcrustacean zooplankton was collected monthly at stations A to E. A weighted
plankton net (mouth diameter 25 cm; mesh size 250 μm; filtration coefficient 0.63) was
towed from the bottom to the surface at each station, at a tow speed of 1 m sec^{-1}. A single
tow was conducted at each station. Microcrustacean zooplankton was preserved with
5% buffered formalin. Some 200 to 350 zooplankters were counted and identified using
a Wild M5A stereo microscope at magnifications of 6x or 12x. The counts included
juvenile and adult cladocerans and adult calanoid copepods. The density of a species
(individuals l^{-1}) in the reservoir was calculated as the arithmetic mean of the densities of
the species at each sampling station.

Microcrustacean Zooplankton Gut Contents

   Microcrustacean zooplankton samples were collected monthly from 0.5-1.0 m
depth between station B and D, with a conical plankton net (mouth diameter 45 cm;
mesh size 200 μm), at a tow speed of 1 m sec^{-1}. The samples were preserved with 10%
buffered formalin. From each sample, a maximum of 20 individuals of each cladoceran
species and calanoid copepods were selected randomly. The animals were cleared, using
sodium hypochlorite (Infante, 1978b) and analysis of gut contents followed Gliwicz
(1969). Phase contrast illumination revealed ingested phytoplankton. Proportional
occurrence of the ingested phytoplankton was calculated as described by Nadin-Hurley
and Duncan (1976).

RESULTS

Physicochemical Parameters

   Total monthly rainfall was erratic ranging from 5 to 374 mm month^{-1} with a maxi-
mum causing a flood in August 1986 (Fig. 2). Secchi disc measurements ranged from 0.2
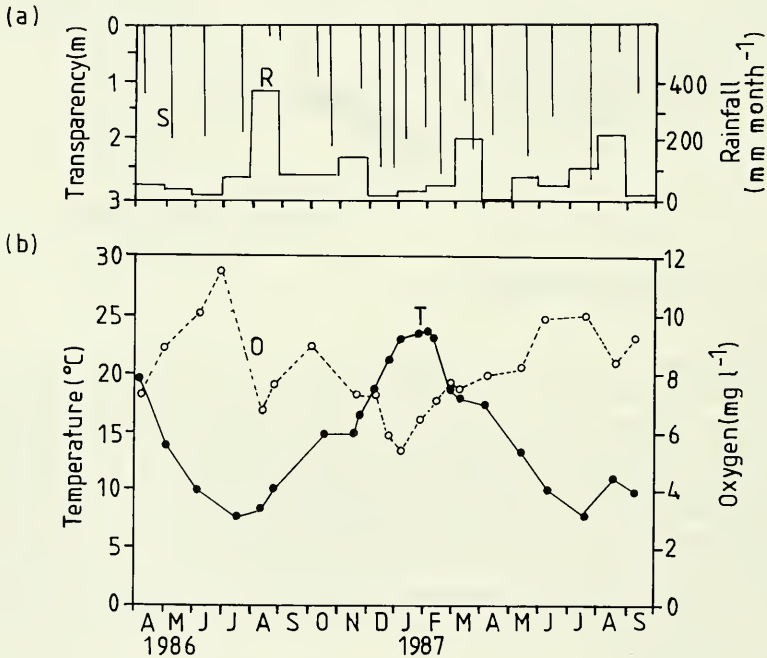to 2.7 m.

Fig. 2. Physicochemical conditions in Wallerawang Reservoir: (a) Secchi disc transparency (S) and rainfall
(R); (b) depth-averaged temperature (T) and Oxygen (O).

   The depth-averaged Kd(PAR) ranged from 0.82 to 6.63 ln units m^{-1} (minimum on
25 July 1987; maximum on 28 August 1986) (Table 2). The depth of 1% PAR ranged
from 0.7 to 5.4 m, suggesting considerable seasonal fluctuations in euphotic depth.

The strong correlation between this depth and water transparency ($r = 0.95$, $n = 10$, $p < 0.001$: $y = 0.24 + 2.02x$ where $y =$ depth of 1% PAR in metres and $x =$ depth of transparency in metres) indicated that light penetration was controlled not by water colour but by suspended solids (Geddes, 1984a).

TABLE 2

Light penetration at station A in Wallerawang Reservoir: Ed(O), downward irradiance just below the surface; Kd, vertical attenuation coefficient for downward irradiance; 1% level, euphotic depth

Date	Time hrs	Ed(O) $\mu Em^{-2}s^{-1}$	Kd m^{-1}	1% level m
11 June 1986	1500	250	1.19	5.3
28 Aug.	1600	280	6.63	0.7
20 Nov.	1400	100	1.92	2.5
31 Jan. 1987	1700	300	1.29	3.5
20 Mar.	1000	60	0.87	5.4
12 Apr.	1450	300	1.23	3.7
19 May	1400	380	1.08	4.2
25 July	1400	300	0.82	5.4
23 Aug.	1420	350	3.98	1.1
13 Sept.	1200	530	1.56	2.8
Mean	—	—	2.06	3.5

The depth-averaged water temperature ranged from 7.6 to 23.4°C (Fig. 2). A minimum of 7.3°C was recorded at 6 m depth on 25 July 1986 and a surface maximum of 27.4°C on 10 January 1987. In summer the surface and bottom temperature differed (up to 8.2°C on 10 January 1987). The reservoir was isothermal in other seasons.

The depth-averaged dissolved oxygen ranged from 4.8 to 10.2 mg l^{-1} (Fig. 2). Saturation of the surface water with oxygen ranged from 78 to 124% (minimum on 28 August 1986; maximum on 31 January 1987). Surface supersaturation and bottom depletion occurred in summer.

The pH was slightly alkaline, ranging from 6.7 to 7.7 (Table 3). Total phosphorus (TP) ranged from 0.01 to 0.09 mg l^{-1} during the period except on 4 August 1986 and 13 April 1987 when TP was below the detectable level (< 0.01 mg l^{-1}). NO_3-N plus NO_2-N was often below the detectable level (< 0.01 mg l^{-1}). Otherwise, NO_3-N plus NO_2-N ranged sevenfold from 0.10 to 0.73 mg l^{-1}. NH_4-N also ranged sevenfold from 0.01 to 0.07 mg l^{-1} except on 7 October 1986 and 9 March 1987 when NH_4-N was below the detectable level (< 0.01 mg l^{-1}). SiO_2-Si ranged from 0.9 to 8.0 mg l^{-1} during the period.

Phytoplankton

A total of 43 phytoplankton taxa were identified (Table 4). Of these, *Chroococcus* (Cyanophyta), *Asterionella, Attheya, Cyclotella, Stephanodiscus*, and *Melosira* (Bacillario-phyta), and *Dinobryon* (Chrysophyta) were the dominant genera. Unidentified flagellates were also a major component.

Asterionella displayed a sharp population peak in spring 1986 (Fig. 3). A maximum of 6080 cells ml^{-1} was recorded in October; it then declined, but again increased moderately in autumn 1987 (maximum 90 cells ml^{-1} in May 1987). *Cyclotella* and *Stephanodiscus* displayed two growth peaks. The first peak, which coincided with that of *Asterionella*, occurred in spring 1986, with a maximum of 330 cells ml^{-1}. The second high peak occurred in late autumn 1987, with a maximum of 9980 cells ml^{-1} in June 1987. *Chroococcus* increased in early summer 1986 to a December maximum of 900 cells ml^{-1}.

TABLE 3

Nutrients and pH at surface at station A in Wallerawang Reservoir: pH: total phosphorus (TP); nitrate plus nitrite
(NO_3-N + NO_2-N); ammonia (NH_4-N) and silica (SiO_2-Si).
Data are from the Electricity Commission of New South Wales

Date	pH	TP (mg l^{-1})	NO_3-N + NO_2-N (mg l^{-1})	NH_4-N (mg l^{-1})	SiO_2-Si (mg l^{-1})
14 Apr. 1986	7.5	0.05	0.00	0.05	4.0
12 May	7.5	0.04	0.00	0.01	2.4
10 June	7.7	0.02	0.00	0.02	1.9
01 July	7.6	0.03	0.00	0.04	0.9
04 Aug.	7.7	0.00	0.10	0.02	0.9
01 Sept.	6.7	0.06	0.66	0.04	6.2
07 Oct.	7.4	0.01	0.24	0.00	5.2
03 Nov.	7.5	0.08	0.11	0.01	3.1
08 Dec.	—	0.08	—	—	—
09 Feb. 1987	7.6	0.03	0.00	0.07	8.0
09 Mar.	7.2	0.05	0.00	0.00	6.6
13 Apr.	7.4	0.00	0.45	0.06	6.5
18 May	7.2	0.02	0.73	0.03	4.5
15 June	7.4	0.02	0.00	0.01	1.9
13 July	7.5	0.06	0.59	0.01	2.0
10 Aug.	—	0.09	—	—	—
14 Sept.	—	0.03	—	—	—
Mean	7.4	0.04	0.21	0.03	3.9

TABLE 4

Phytoplankton in Wallerawang Reservoir between August 1986 and September 1987

Cyanophyta
  Chroococcus spp.
  Dactylococcopsis spp.
  Oscillatoria sp.
  Anabaena sp.

Chlorophyta
  Volvox spp.
  Botryococcus sp.
  Pediastrum spp.
  Oocystis spp.
  Selenastrum ?minutum (Naeg.) Collins
  Closteriopsis longissima Lemmermann
  Schroederia ?setigera (Shroeder)
        Lemmermann
  Scenedesmus spp.
  Closterium sp.
  Cosmarium spp.
  Quadrigula spp.
  Staurastrum spp.

Euglenophyta
  Trachelomonas sp.

Chrysophyta
  Dinobryon divergens Imhof
  Dinobryon cylindricum Imhof

Bacillariophyta
  Melosira granulata (Ehrenb.) Ralfs
  Melosira granulata var. *angustissima* Muller
  Melosira italica (Ehrenb.) Kutz.
  Melosira varians Agardh
  Cyclotella spp.
  Stephanodiscus spp.
  Attheya sp.
  Tabellaria sp.
  Fragilaria sp.
  Asterionella spp.
  Synedra pulchella Kutz.
  Synedra sp.
  Navicula spp.
  Pinnularia sp.
  Gomphonema acuminatum var. *coronatum* (Ehrenb.) Babenhorst
  Gomphonema constricutum Ehrenberg
  Gyrosigma sp.
  Cymbella spp.
  Nitzschia sp.
  Surirella spp.

Pyrrhophyta
  Peridinium sp.
  Ceratium hirundinella O. F. Muller
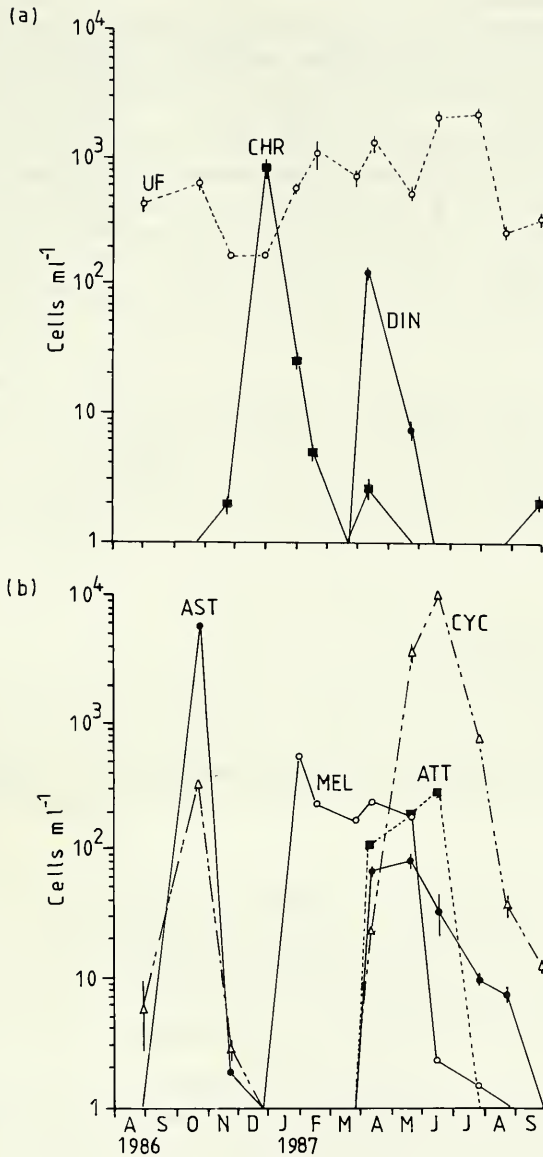
Unidentified flagellates
Unidentified algae

Fig. 3. Density of phytoplankton in Wallerawang Reservoir: (a) *Chroococcus* (CHR), *Dinobryon* (DIN) and unidentified flagellates (UF); (b) diatoms *Asterionella* (AST), *Attheya* (ATT), *Cyclotella/Stephanodiscus* (CYC) and *Melosira* (MEL). Mean ± SE is shown: n = 5 except 29 August and 23 October 1986 when n = 4.

Melosira (mostly *M. granulata*) became abundant from summer to autumn (maximum 540 cells ml^{-1} in January 1987). In autumn 1987, *Dinobryon* (mostly *D. divergens*) produced a weak growth peak of 130 cells ml^{-1} in late autumn (June) 1987. The unidentified flagellates (probably three species in total; maximum cell width 3-20 μm) occurred throughout the study; their density fluctuated irregularly from 160 to 2240 cells ml^{-1} (minimum in December 1986; maximum in July 1987).

Microcrustacean Zooplankton

A total of 12 cladoceran and 3 calanoid species were identified (Table 5). Of these, the dominant cladocerans were *Bosmina meridionalis*, *Ceriodaphnia* sp., and *Daphnia carinata*, while the dominant calanoid copepods were *Calamoecia lucasi*, *Boeckella minuta*, and *Boeckella triarticulata*.

B. meridionalis occurred scarcely throughout the study except in January 1987 (Fig. 4). The density of this small cladoceran species may be greatly underestimated by the large mesh (250 μm), used in the sampling. *Ceriodaphnia* was a spring-early summer species. A maximum of 5.5 l^{-1} was recorded in November 1986. *D. carinata* was a spring-summer species in 1986, but also increased in winter 1987. During the first growth period (July 1986 to March 1987), *D. carinata* reached a maximum of 21.1 l^{-1} in December 1986. The second growth period commenced in July 1987, with a maximum of 22.3 l^{-1} in August.

C. lucasi was perennial, though its abundance fluctuated. A sharp decline was observed after the August 1986 flood. A minimum of 0.1 l^{-1} and a maximum of 30.4 l^{-1} were recorded in August 1986 and in July 1987, respectively. *B. minuta* was also perennial. Its abundance fluctuated like *C. lucasi*. A minimum of 0.3 l^{-1} and a maximum of 45.9 l^{-1} were recorded in August 1986 and in July 1987, respectively. *B. triarticulata* occurred from spring to early summer. A maximum of 4.2 l^{-1} was recorded in December 1986.

Microcrustacean Zooplankton Gut contents

A total of 240 *Bosmina*, 80 *Ceriodaphnia*, 160 *Daphnia*, 330 *Calamoecia*, 340 *B. minuta*, and 80 *B. triarticulata* guts were examined, yielding 11, 10, 15, 18, 29 and 21 phytoplankton components, respectively (Table 6). Most phytoplankton genera in Wallerawang Reservoir were represented, except *Anabaena*, *Volvox*, *Closterium*, *Shroederia*, *Gyrosigma* and flagellates which were not detected in the zooplankton guts.

TABLE 5

Cladocerans and calanoid copepods in Wallerawang Reservoir
between April 1986 and September 1987

Cladocerans
  Diaphanosoma unguiculatum Gurney
  Pleuroxus cf. *inermis* Sars
  Chydorus sphaericus s.1. (Muller)
  Pseudochydorus cf. *globosus* (Baird)
  Alona diaphana King
  Leydigia leydigi (Schoedier)
  Ilyocryptus sordidus (Lieven)
  Bosmina meridionalis Sars
  Daphnia carinata s.1. King
  Simocephalus vetulus elisabethae (King)
  Ceriodaphnia cornuta Sars
  Ceriodaphnia sp.

Calanoid copepods
  Boeckella triarticulata Thomson
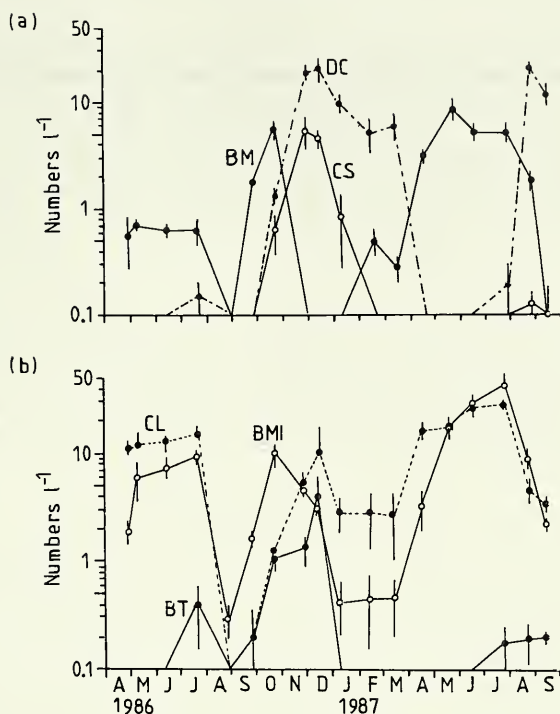 *Boeckella minuta* Sars
  Calamoecia lucasi Brady

Fig. 4. Density of microcrustacean zooplankton in Wallerawang Reservoir: (a) cladocerans *Bosmina meridionalis* (BM), *Ceriodaphnia* sp. (CS) and *Daphnia carinata* (DC); (b) calanoid copepods *Calamoecia lucasi* (CL), *Boeckella minuta* (BMI) and *Boeckella triarticulata* (BT). Mean ± SE is shown: n = 5.

(a)   *Bosmina meridionalis*

The dominant diet components were *Cyclotella* and *Stephanodiscus* (32%), *Chroococcus* (16%) and *Oocystis* (16%) (see Kobayashi, 1990 for full data). There was a significant positive correlation between the proportional occurrence of centric diatoms (*Cyclotella* and *Stephanodiscus*) in the *Bosmina* guts and their density in the plankton (Spearman's rank correlation coefficient or r_s = 0.92, n = 7, p < 0.05). *Cyclotella* and *Stephanodiscus* were well digested. Ingested *Chroococcus* and *Oocystis* were often unicellular and intact.

(b)   *Ceriodaphnia* sp.

Chroococcus (41%) and *Oocystis* (25%) dominated the components. *Chroococcus* was abundant in the *Ceriodaphnia* guts in January 1987 when this blue-green alga also peaked in the plankton. Most of the ingested *Chroococcus* were intact in the *Ceriodaphnia* guts.

(c)   *Daphnia carinata*

The dominant components were *Chroococcus* (62%), *Oocystis* (44%), *Botryococcus* (25%) and centric diatoms (*Cyclotella* and *Stephanodiscus* (20%). *Chroococcus* constituted the main dietary phytoplankton component for *Daphnia* in summer 1986 to 1987, as observed in *Ceriodaphnia*. Ten to 80 colonies (800 to 6000 cells) of *Chroococcus* were found in each gut of *Daphnia* in December 1986 when *Chroococcus* propagated in the reservoir. *Chroococcus* cells were mostly intact in the *Daphnia* guts. Of other algae, *Trachelomonas* was detected in 14%; the ingested brown shells and cell tissues inside the shells often remained intact. Large *Staurastrum* and *Ceratium* were fragmented in the guts.

TABLE 6

Dietary phytoplankton components in the guts of microcrustacean zooplankton in Wallerawang Reservoir between April 1986 and September 1987: Bosmina meridionalis (BM); Ceriodaphnia *sp.* (CS); Daphnia carinata (DC); Calamoecia lucasi (CL); Boeckella minuta (BMI); Boeckella triarticulata (BT).
Occurrence symbols are: p — present, x — absent

Taxonomic Grouping	BM	CS	DC	CL	BMI	BT
Cyanophyta						
Chroococcus	p	p	p	p	p	p
Dactylococcopsis	p	x	x	x	p	p
Oscillatoria	x	x	x	x	p	x
Chlorophyta						
Botryococcus	x	x	p	x	x	x
Closteriopsis	x	x	x	x	p	p
Cosmarium	p	x	p	p	p	x
Mougeotia	x	x	x	p	x	p
Oocystis	p	p	p	p	p	p
Pediastrum	x	x	x	x	x	p
Quadrigula	p	x	p	p	p	p
Scenedesmus	p	p	p	p	p	p
Selenastrum	p	x	x	p	p	x
Staurastrum	x	x	p	x	p	p
Euglenophyta						
Trachelomonas	x	p	p	x	p	p
Chrysophyta						
Dinobryon	x	x	x	x	p	p
Bacillariophyta						
Asterionella	x	p	p	p	p	p
Attheya	x	x	x	x	p	x
Cocconeis	x	x	x	x	p	x
Cyclotella/Stephanodiscus	p	p	p	p	p	p
Cymbella	p	p	p	p	p	p
Fragilaria	x	x	x	x	p	x
Frustulia	x	x	x	p	p	x
Gomphonema	x	x	x	p	p	p
Melosira	p	x	p	p	p	p
Navicula	x	p	x	p	p	p
Nitzschia	x	x	x	x	p	x
Pinnularia	x	x	x	p	p	x
Surirella	x	x	x	x	p	x
Synedra	x	p	p	p	p	p
Tabellaria	x	x	x	x	p	p
Pyrrhophyta						
Ceratium	x	x	p	x	x	x
Peridinium	x	x	x	p	p	p
Unidentified algae	p	p	p	p	p	p

(d) *Calamoecia lucasi*

The dominant components were *Oocystis* (41%), *Cyclotella* and *Stephanodiscus* (37%), and *Chroococcus* (20%). The unicellular *Oocystis* was occasionally digested, while the colonial form was mostly intact in the *Calamoecia* guts. The proportional occurrence of centric diatoms and *Chroococcus* in the *Calamoecia* guts was significantly correlated with the algal density in the plankton ($r_s = 0.74$ and 0.84, n=12, $p < 0.05$ and < 0.001, respectively).

(e)   *Boeckella minuta*

The dominant components were *Cyclotella* and *Stephanodiscus* (55%), *Oocystis* (49%), *Chroococcus* (33%), *Melosira* (21%), and *Asterionella* (21%). There was a significant positive correlation between the proportional occurrence of *Cyclotella* and *Stephanodiscus*, and *Chroococcus* in the guts of *B. minuta* and their density in the plankton (r_s = 0.83 and 0.63, n = 12, p < 0.001 and < 0.01, respectively). *Oocystis* was abundant in early autumn 1986 and 1987. Large *Asterionella* was abundant in the guts of *B. minuta* in spring 1986 and in autumn 1987. *Melosira* was abundant in autumn 1986 and 1987. Of other algae, *Synedra* was detected in 14%.

(f)   *Boeckella triarticulata*

The dominant components were *Chroococcus* (53%), *Oocystis* (49%), *Asterionella* (49%), and centric diatoms (*Cyclotella* and *Stephanodiscus*) (34%). *Chroococcus* and *Oocystis* predominated in early summer 1986, and *Asterionella* in spring 1986 when it was abundant in the plankton. Large *Staurastrum* and *Pediastrum* were fragmented in the guts of *B. triarticulata*.

DISCUSSION

Physicochemical Parameters

Fluctuations in water transparency of Wallerawang Reservoir mainly followed rainfall. The Secchi disc depth of 0.2 to 2.7 m and depth-averaged Kd(PAR) of 0.82 to 6.63 ln units m^{-1} were within the values recorded in other Australian inland waters (Kirk, 1986). In that reservoir mean depth is 3.4 m, the depth of 1% PAR (euphotic depth) of 0.7 to 5.4 m (mean 3.5 m) suggests that light is not a limiting factor for algal growth except after floods.

Persistent thermal stratification did not develop in summer. Since the reservoir is relatively shallow, wind action prevents stratification and development of a thermocline (Hergenrader and Hammer, 1973). The depletion of summer bottom oxygen was also temporary.

The pH values were generally stable in the range 7.2-7.7, except that in September 1986 (pH 6.7). Lowered pH then was probably due to a flow of low-pH flood water (Timms, 1969).

TP was generally within the mesotrophic to eutrophic level (Sakamoto, 1966). The mean TP (0.04 mg l^{-1}) is lower than that of Australian eutrophic waters: 0.089 mg l^{-1} in Lake Daylesford, Victoria (Bales *et al.*, 1980, calculated from their Table 1) and 233 mg m^{-3} in Lake Alexandrina, South Australia (Geddes, 1984a). It is possible that phosphorus may limit algal growth in Wallerawang when nitrogen is high. However, this situation does not occur very often at Wallerawang. Dissolved inorganic nitrogen (NO_3-N plus NO_2-N and NH_4-N) reached relatively high concentrations in spring 1986 and 1987 (maximum 0.76 mg l^{-1} in May 1987), but was mostly low to depleted (< 0.10 mg l^{-1}) during the rest of the period studied. NO_3-N and NH_4-N are readily used for algal growth (Golterman, 1975). Thus relatively high dissolved inorganic nitrogen in spring 1986 and 1987, coupled with increasing water temperature, provided the growth of phytoplankton. SiO_2-Si (mean 4.6 mg l^{-1}) was sufficient for the growth of diatoms, particularly from late winter 1986 to autumn 1987 when SiO_2-Si was over 3 mg l^{-1} (Lund, 1965).

Phytoplankton

Phytoplankton in Wallerawang Reservoir followed a seasonal succession of the dominant genera characteristic of other unstratified, mesotrophic lakes (Reynolds,

1980): *Asterionella*, *Cyclotella* and *Stephanodiscus* (spring), *Chroococcus* (early summer), *Melosira* (summer to autumn), *Dinobryon* and *Asterionella* (autumn), *Attheya* and again *Cyclotella* and *Stephanodiscus* (late autumn). In addition, the unidentified flagellates were abundant throughout the study.

    Asterionella, a common diatom in the spring bloom (Goldman and Horne, 1983) and centric diatoms (*Cyclotella*, *Stephanodiscus*) were the first phytoplankton to increase after the August 1986 flood. These diatoms tolerate low light availability (Wetzel, 1975). The summer blooms of *Chroococcus* and *Melosira* (mostly *M. granulata*) are characteristic of mesotrophic to eutrophic waters (Hutchinson, 1967; Reynolds, 1980). The increase in water temperature during summer was important for the growth of *Melosira*; its density was significantly correlated with surface water temperature (r=0.68, n=13, F=9.63, p<0.01). It is also abundant in Warragamba, Cataract and Prospect Reservoirs, N.S.W. (Thomasson, 1973), and the lower River Murray, South Australia (Shiel *et al.*, 1982). The propagation of *Dinobryon* in early autumn was correlated with low phosphorus with TP<0.02 mg l^{-1} (Hutchinson, 1967).

    Microcystis, recorded by Elcom, N.S.W. in 1983 and 1984, was not recorded in Wallerawang phytoplankton during this study. Its absence was probably due to lack of persistent thermal stratification (Reynolds, 1980) and depleted dissolved inorganic nitrogen (Gerloff and Skoog, 1954, 1957; Takahashi *et al.*, 1981) in late summer. However, these conditions, coupled with moderately high silica during the period (SiO_2-Si 6.6 to 8.0 mg l^{-1}), should have supported the abundance of *Melosira* in the reservoir (cf. Lund, 1954; Kilham, 1971; Reynolds, 1980).

Microcrustacean Zooplankton

    The dominant cladocerans and calanoid copepods in Wallerawang Reservoir are ubiquitous species in south-eastern Australia (Mitchell, 1986; Timms, 1970a, 1970b, 1987).

    Small-bodied *B. meridionalis*, which is often a perennial species (Timms, 1970b; Shiel *et al.*, 1982; Geddes, 1984b), diminished during summer 1986 when the medium-bodied *Ceriodaphnia* and the large-bodied *D. carinata* increased. However, *B. meridionalis* again increased during autumn 1987, with decreasing *Ceriodaphnia* and *D. carinata*. Although zooplankton competitive ability is a complex interplay between size-selective vertebrate and invertebrate predation, reproductive rate, and growth rate (Mitchell and Williams, 1982), the shift from small- to large-bodied cladoceran species in Wallerawang Reservoir may be explained by the size-efficiency hypothesis (Brooks and Dodson, 1965).

    To date, there is insufficient information available on the effects of vertebrate and invertebrate predation on zooplankton. The author has observed small flathead gudgeon (*Philypnodon grandiceps*) preying on small-bodied chydorids, *Bosmina* and cyclopoids in Wallerawang Reservoir, but the contribution of larger fish species is unknown.

    The highest abundance of *D. carinata* around 11 to 19°C was consistent with Hebert (1977), Mitchell and Williams (1982), who described the species as a cold- to cool-water form. No individuals of *D. carinata* developed crests throughout the study, suggesting low notonectid predation (Grant and Bayly, 1981).

    The coexisting and perennial occurrence of small-bodied *C. lucasi*, and medium-bodied *B. minuta* was consistent with Timms (1970a, 1970b). A significant positive correlation between their densities (r_s=0.73, n=18, p<0.01) indicates that competition between these two calanoid copepods is weak or absent.

    The densities of microcrustacean zooplankton (cladocerans plus calanoid copepods) in Wallerawang Reservoir, ranging from 0.5 to 82.1 l^{-1} (mean 27.2 l^{-1}), are

lower than those in Lake Alexandrina (35 to 123 l⁻¹; mean 66 l⁻¹) (Geddes, 1984b), but similar to those in Lake Hume (10 to 60 l⁻¹) (Walker and Hillman, 1977 as quoted in Geddes, 1984b). In turbid Lake Alexandrina, the high zooplankton population biomass is believed to be maintained by the constant availability of abundant detrital particles and bacteria (Geddes, 1984b). Floods may temporarily produce similar food conditions for microcrustacean zooplankton in Wallerawang Reservoir.

Large Flood Influence (August 1986)

This flood resulted in the lowest transparency, highest depth-averaged Kd(PAR) value and therefore, shallowest euphotic depth found in the reservoir. Jolly (1966) reported similar erratic optical properties of flooded reservoirs in eastern N.S.W. The drop in pH and increase in nutrients were also probably flood-induced (Timms, 1969; Geddes, 1988).

Phytoplankton populations were very scarce except unidentified flagellates which may have come from Cox's River or have been resuspended from sediments. Holoplanktonic *Asterionella* and the small unicellular centric diatoms dominated phytoplankton two months after the flood. Increased silica and moderately improved light availability appeared to have supported the growth of these diatoms (Goldman and Horne, 1983).

The flood also lowered microcrustacean zooplankton density in Wallerawang Reservoir. It took one to two months for cladocerans and calanoid copepods (except *C. lucasi*) to recover after the flood (Jolly, 1966; Timms, 1970b).

Microcrustacean Zooplankton Gut Contents

Comparing the detritus and/or bacteria based zooplankton in the Alligator Rivers region (Tait *et al.*, 1984) and Lake Alexandrina (Geddes, 1984b, 1988), the frequent presence of phytoplankton in the guts of Wallerawang zooplankton is significant; diatoms (*Asterionella, Cyclotella, Melosira,* and *Stephanodiscus*) were particularly abundant, and were well digested in the zooplankton guts during the study. However, this does not necessarily imply that they should also constitute an important energy pass between phytoplankton and zooplankton in the reservoir. Rapid consumption but with poor assimilation efficiency of *Asterionella* by *Diaptomus* is reported by Schindler (1971). The food value of *Melosira* is species-dependent, but *Stephanodiscus* supports high growth rate and reproduction of zooplankton (Infante and Litt, 1983). The gelatinous blue-green alga *Chroococcus* and the green alga *Oocystis* were also frequently ingested, but were mostly intact. They passed probably unharmed through zooplankton guts (Porter, 1975; Infante, 1978a; Sarnelle, 1986), showing no significant response to grazing (Merrick and Ganf, 1988).

Burns *et al.* (1989) reported that the calanoid *Boeckella* ingested *Anabaena* in some New Zealand lakes, however no *Anabaena* was found in the guts of *B. minuta* and *B. triarticulata* in Wallerawang Reservoir. *Oscillatoria* was found only once in the guts of *B. minuta* during the study. *Volvox, Closterium,* and *Gyrosigma* were absent in the zooplankton guts; they were too big for the zooplankton (Burns, 1968). Flagellates, which are generally of high food value (Schindler, 1971; Sarnelle, 1986), were also never detected in the zooplankton gut contents, even though they were abundant in the plankton, and were within the ingestible cell size for the zooplankton. Perhaps they were ingested, but were disrupted and rendered unrecognizable (Infante, 1978a).

ACKNOWLEDGEMENTS

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